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Effects of Mechanical Properties of Fabrics on Clothing Pressure

***Abstract**. To investigate how elastic modulus, elongation and relaxation time of fabric influence clothing pressure, the pressure on cylinder model was measured. The fabrics used were cotton spandex and polyester spandex elastic knitted fabric. The fabrics were sewed as 100mm high cylinders. The fabric cylinders with different elongation and with elongation 20% at different relaxation time pressed the cylinder model, and the pressure was measured. By analyzing data, it was found that clothing pressure increases linearly with the increase of fabric elongation basically when fabric elongation was within 60% . The clothing pressure exerted by fabric whose elastic modulus is greater is generally higher than that by fabric whose elastic modulus is lower when elongation was the same. The clothing pressure presents a trend of first order exponential decay with the passage of relaxation time, and the main pressure decrease happens within the first 30 minutes, subsequently, the pressure decreases slowly and tends to be stable ultimately. And the decrease caused by relaxation properties of fabric accounts for a little of total pressure.*

***Streszczenie.** W artykule badaniom poddano cylindryczny model, wykonany z różnych rodzajów materiału. Oceniono wpływ współczynnika elastyczności, czas wydłużenia i ściągnięcia na ciśnienie wywierane przez tkaninę. Analiza danych wykazała, że wywierane ciśnienie rośnie liniowo wraz ze wzrostem wydłużenia, zwłaszcza do 60%. Ponadto jego zanik ma charakterystykę wykładniczą pierwszego rzędu a główny spadek następuje w ciągu pierwszych 30min potem opada wolno. (**Wpływ własności mechanicznych tkanin na nacisk ubrań**).*

Keywords: elastic modulus, elongation, relaxation time, cylinder model
Słowa kluczowe: współczynnik elastyczności, wydłużenie, czas relaksacji, model cylindryczny.

Introduction

Clothing pressure is one of the most important indicators which are used to evaluate clothing comfort. A lots of researches related to clothing pressure have been published. Jeong et al. found that constant skin pressure exerted by an all-in-one woman's foundation garment during daytime could make a decrease in the rectal temperature at night and suppress the secretion of urinary melatonin [1]. Lai et al. made a validation study on the application of a recently developed device, the Pliance X System, which was used for measuring the static low interface pressure [2]. Chan et al. predicted optimal pressure distribution by studying the relationship between the compressive feeling and clothing pressure of tight girdle [3]. Mirjalili et al. proved that ANSYS software could compute contact pressures with enough accuracy in different cases of geometrical complexity by studying the contact pressure between an elastic garment and some parts of the human body whose geometries were cylindrical and conical [4]. Zhang et al. pointed out that the space allowance between human body and garment had a great relationship with clothing pressure, when the space allowance was less than or equal to zero, clothing pressure could be generated [5]. Denton found that clothing pressure increased with the increase of the curvature of the human body [6]. Harumi et al. studied that clothing pressure was affected by the movement, posture, breathing and BMI of human body, and the higher BMI of human body was, the greater clothing pressure would be. They also found that clothing pressure was influenced by the materials of cup-stand and the lower tensile resistance of the materials of brassieres was, the smaller clothing pressure would be [7, 8]. Pratt et al. stated that there were three factors which influenced clothing pressure exerted by garments, body shape, type and age of the fabric used, design and fit of the garment [9]. Liu et al. created a finite element model of standard female body bust cross-section composed of skin, soft tissue and bone, based on the model, the clothing pressure exerted on subjects' busts by elastic sports vest was studied[10]. However, there have been few papers about the investigation of the effects of mechanical properties of fabrics on clothing pressure. Therefore, in this research, we focused on studying the effects of elastic modulus, elongation and relaxation properties of fabrics on clothing pressure.

Experimental apparatus

The present study was undertaken to measure fabric properties by using a universal testing machine (LRXPLUS), developing by LLOYD company in UK. The crosshead distance was 50 mm, the crosshead speed was 100 mm/min. Computer control technology was used by the equipment, which could collect data automatically. The sensor has the function of automatic diagnosis and automatic calibration checks. The equipment can be used for mechanical performance test of tensile, bending, compression properties for some materials, and can provide all kinds of testing curves. The universal testing machine (LRXPLUS) is shown in Figure 1.

Fig.1.The universal testing machine (LRXPLUS)

The clothing pressure was measured by a pressure measuring device (AMI3037 S-5) supplied by AMI Limited Company in Japan. Pressure measuring device (AMI3037 S-5) is pneumatic-typed pressure testing device. When clothing pressure is measured, an air sac lies on measurement site as sensing parts, whose thickness is about 2 mm. The clothing pressure induced by sensing parts is imputed into input, and sensor output outputs voltage signal. Then the signal is processed by special voltage amplifier, and the change of clothing pressure is checked through the change of voltage. The precision of the device is 0 ～ 14.00kPa±0.1kPa, 14.00 ～ 34.00±0.25kPa. The pressure measuring device is shown in Figure 2.

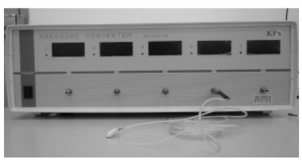


Figure 2. Pressure measuring device (AMI3037 S-5)

Materials and Methods

Fabric tests.The fabrics used were cotton/ spandex and polyester/ spandex knitted fabric in this experiment, which are used widely for tight garments, the basic parameters of the fabrics are shown in Table 1.

Table 1. The basic parameters of the fabrics

Samples	Surface density（g/m^2）	Fiber content (%)
c/s knitted fabric	180	c/ s (95/5)
p/s knitted fabric	123	p/ s (95/5)

Note:c denotes cotton,s denotes spandex,and p denotes polyester.

Tensile tests were carried out to calculate and investigate the elastic modulus of the two fabrics in weft and warp directions, respectively. The width of samples was selected as 10mm limited by chuck width, the effective length of samples was selected as 50mm, and 25 mm allowance on both sides was left for gripping. The specimens were conditioned at a temperature of 20±2□ and humility of 65±3％ for more than 24 hours.

Clothing pressure tests.The clothing pressure exerted by the fabrics with different elongation and with elongation 20% at different relaxation time was measured in this study. The experiment was carried out on the cylinder model, which was used to simulate some parts of the human body whose geometries are cylindrical, such as: waist, abdomen, limbs, etc. In order to make the elastic modulus of the cylinder model be close to that of human body, the interior of model was selected as hard PVC pipe which was equivalent to human skeleton, and the external was selected as 5mm thick soft polyurethane foam which was equivalent to human subcutaneous tissue [11]. Considering the saving of fabric and the accuracy of experiment, the circumference of cylinder model was chosen as 462mm (be equal to thigh circumference). In this research, fabric samples were sewed as 100mm high cylinders whose circumferences were different. Consider that the elongation range is no more than 60% generally when a person is putting on a tight garment [12]. Therefore, in this research, only fabric elongation range from 0% to 60% was studied in fabric tensile test and the experiment for the effect of fabric elongation on clothing pressure. The sample circumferences l with different elongation were calculated on the basis of Eq.(1), the different elongation was selected as 0%, 10%，20%，30%，40%，50%，60%.

(1) $$l = \frac{l_0}{1+\varepsilon}$$

where l is sample circumferences, l_0 is original sample circumference, ε is fabric elongation. The clothing pressure exerted by the sewed samples with different elongation was measured, respectively. When the fabric elongation was 20%, the relaxation of clothing pressure were measured, the relaxation time was selected as 0min，10min，20min，30min，60min，90min，120min，200min, 300min, 600min, 900min, 1200min.

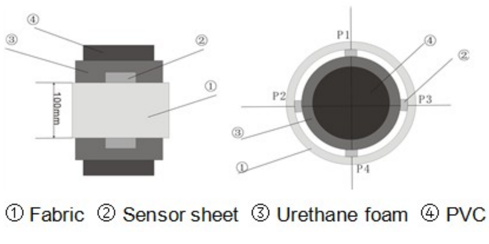


Fig.3. Measurement model of clothing pressure

In order to measure the pressure induced by the fabrics, pressure sensors were placed between cylinder model and fabric. The pressure was recorded when data was relatively stable. In this research, the pressure exerted on four relative positions (p1, p2, p3, p4) of the cylinder model was taken and the average data was regarded as final pressure. The flat and vertical views of the measurement model are shown in Figure. 3.

Results and Discussion

The elastic modulus of fabrics.Figure 4 shows load-extension curves of any one out of five samples of each fabric.

It can be seen from figure 4 that tensile load and fabric extension present linear relationship generally when the extension is between 0mm and 20 mm (elongation is within 40%). Because the universal material testing machine(LRXPLUS) starts to record data from elongation around 1% automatically, so we chosen the data recorded firstly to the data of elongation 40% to calculate the elastic modulus of fabrics.

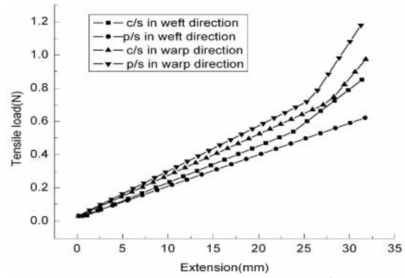


Figure.4 The load - extension curves of c / s knitted fabric and p / s knitted fabric in weft and warp direction

The elastic modulus of five samples of each fabric was all calculated, and the average value of each fabric was also calculated and regarded as the final elastic modulus of each fabric, which is listed in Table 2.

Table 2. The elastic modulus of each fabric

	c/s in weft direction	p/s in weft direction	c/s in warp direction	p/s in warp direction
E (N/mm)	0.024	0.019	0.026	0.028

Note: E denotes elastic modulus

It can be seen from Table 2 that the elastic modulus of fabrics from large to small is p/s in warp direction, c/s in warp direction, c/s in weft direction and p/s in weft direction. Combining Table 2 with Figure 4, it can be seen that the fabric whose elastic modulus is greater needs more load to achieve the same extension in fabric extension. On the contrary, the fabric whose elastic modulus is lower needs smaller load. This can be explained by the fact that fabric tensile deformation is linear elastic deformation basically in our study range, so the load in fabric extension can be calculated on the basis of the Eq.(2),

(2) $$T = fl'$$

Where T denotes fabric load, f denotes elastic modulus, l' denotes fabric extension. So when fabric extension l' is the same, the fabric whose elastic modulus is greater needs more load.

Effects of elastic modulus and elongation of fabrics on clothing pressure.The clothing pressure exerted by the fabrics under different elongation is revealed in Figure 5.

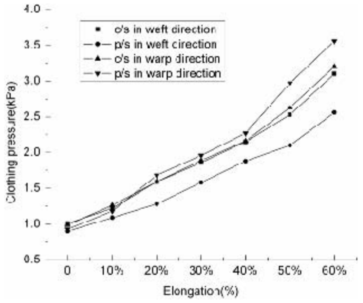


Fig..5 The clothing pressure exerted by c / s knitted fabric and p / s knitted fabric under different elongation in weft and warp direction

It can be seen from Figure 5 that the clothing pressure exerted by each fabric increases with the increase of fabric elongation. And the clothing pressure from large to small is p/s in warp direction, c/s in warp direction, c/s in weft direction and p/s in weft direction when fabric elongation is the same. The reason for this phenomenon is that the change of clothing pressure has a close relationship with fabric extension, the change of fabric extension reflects the change of pressure exerted by fabric indirectly. When human body is in tight clothing, some limits to human body is caused by fabric, which can cause fabric extension and produce fabric tension (tensile load) T . And the clothing pressure F (vertical force of human body surface) is caused by T . The physical analysis diagram of clothing pressure is shown in Figure 6. When the fabric elongation is within 60%, fabric deformation is linear elastic deformation basically, so the relationship between T and F can be regarded as Eq.(3) [13].

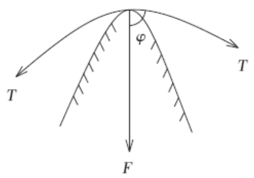


Figure.6 The Physical analysis figure of clothing pressure

(3) $$F = 2T\cos\varphi = 2fl'\cos\varphi$$

Where T denotes fabric load, F denotes clothing pressure, f denotes elastic modulus, l' denotes fabric extension, φ denotes the angle between fabric load T and clothing pressure F .

Therefore, clothing pressure has relationship with the elastic modulus of fabric, fabric extension, and dressing parts mainly. At the same part, the clothing pressure exerted by the fabric whose elastic modulus is bigger is higher when fabric extension is the same.

Figure 7 displays the fitted lines between clothing pressure and fabric elongation, the fitted linear equations between the two is listed in Table 3.

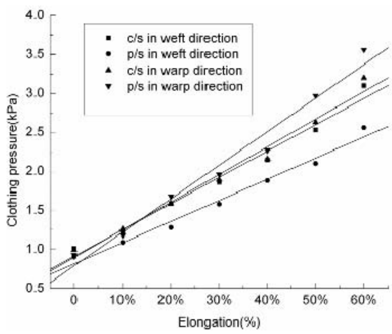


Fig.7. The fitted lines between clothing pressure and fabric elongation

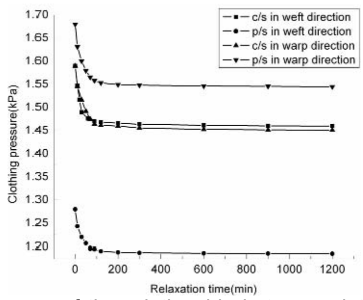
Table.3 The fitted linear equations between clothing pressure and fabric elongation

Samples	Fitted equations	R^2
c/s in weft direction	$F = 0.3375\varepsilon + 0.57286$	0.98196
p/s in weft direction	$F = 0.27143\varepsilon + 0.54143$	0.98337
c/s in warp direction	$F = 0.355\varepsilon + 0.54$	0.97620
p/s in warp direction	$F = 0.43071\varepsilon + 0.35571$	0.97539

Note: F denotes clothing pressure, ε denotes fabric elongation

It can be seen from Figure 7 that the relationship between clothing pressure and fabric elongation presents a good linear relationship. R^2 in Table 3 are all bigger than 0.975, which states that the relationship between clothing pressure and fabric elongation presents a good linear relationship, too. The reason is that the fabric deformation is linear elastic deformation basically when elongation is within 60%.

Effects of elastic modulus and relaxation properties of fabrics on clothing pressure.Figure 8 displays the curves between clothing pressure and relaxation time when fabric elongation was 20%.



Figu.8. The curves of the relationship between clothing pressure and relaxation time

The relaxation of clothing pressure is caused by fabric stress relaxation mainly. Fabric stress relaxation refers to the phenomenon that fabric internal stress or tension decayed with the increase of time when fabric extension was constant [14]. Stress attenuation process of knitted fabric includes yarn appearance change, yarn directional change and stress even. When fabric extension was constant, not all similar yarns in coil have the same stress. Some yarns get higher stress than average for orientation or poor structure, and the other part get lower than average. The fabric is a complete system composed of yarn, so stress even will appear. Stress even can make average stress decrease. Stress even is closely related to fabric deformation, yarn metastasis, contact point metastasis. In addition, the shape change and directional change in some section of yarn can cause the decrease of fabric stress, too.

It can be seen from Figure 8 that clothing pressure decreases gradually to balance with the change of relaxation time under constant elongation. But the main decrease happens within the first 30 minutes. 30 minutes later, the decrease is very slow, after about 600 minutes, the clothing pressure is stable basically. The phenomenon is caused by fabric relaxation property. Fabric relaxation phenomenon has three main stages, fast relaxation stage, slow relaxation stage and stationary stage. In the beginning of the fabric relaxation time, the original balance was broken because of sudden external shocks, leading to uneven yarn stress. The uneven needs urgent adjustment, so fabric stress drops faster in this stage. Along with the adjustment of stress change, some changes of yarn appearance make fabric stress decline gradually, so the fabric stress uneven will decrease gradually, which presents a slow relaxation stage. Subsequently, the stress uneven disappears gradually, the stress tends to a constant value, reaches a new balance, which presents a smooth stage.

It also can be seen from Figure 8 that the decrease of clothing pressure caused by relaxation properties of fabric only accounts for a small part of all. The decrease of clothing pressure caused by relaxation property of fabric whose elastic modulus is smaller is always lower than that by the fabric whose elastic modulus is bigger. So relaxation-resistance of fabric whose elastic modulus is smaller is always better, too. The reason is that the deformation ability of the fabric whose elastic modulus is small is greater than that of the fabric whose elastic modulus is big when tensile load is the same. The deformation of the fabric whose elastic modulus is small recovers easily than that of the fabric whose elastic modulus is big after removing load. To achieve the same fabric elongation, the tension of fabric whose elastic modulus is small is lower, so the yarn tension uneven and material damage caused by external force is smaller, stress even and the decrease of average stress is also smaller under constant extension.

Figure 9 shows the fitted curves of the relationship between clothing pressure and relaxation time which was fitted in Origin 7.5 when fabric elongation was 20%. The fitted equations of the two are listed in Table 4. As shown in Figure 9 and Table 4, the relationship between clothing pressure and relaxation time presents a trend of first order exponential decay.

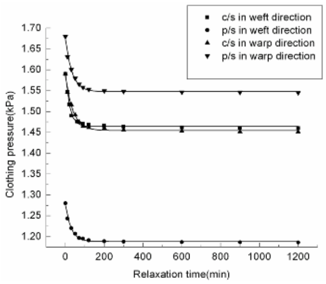


Figure.9 The fitted curves of the relationship between clothing pressure and relaxation time

Table.4 The fitted equations of the relationship between clothing pressure and relaxation time

Samples	Fitted equations	R^2
c/s in weft direction	$F = 1.46412 + 0.12666e\wedge(-t/22.07707)$	0.99247
p/s in weft direction	$F = 1.18825 + 0.08768e\wedge(-t/29.25786)$	0.98958
c/s in warp direction	$F = 1.4544 + 0.13064e\wedge(-t/37.95995)$	0.992
p/s in warp direction	$F = 1.5479 + 0.12581e\wedge(-t/33.91217)$	0.99072

Note: F denotes clothing pressure, t denotes relaxation time

Conclusions

It was concluded that the elastic modulus, elongation and relaxation time of fabric all influence clothing pressure. The clothing pressure exerted by fabric whose elastic modulus is greater is generally higher than that by fabric whose elastic modulus is lower when elongation is the same. The bigger the elongation is, the higher the clothing pressure exerted by the fabric will happen, and clothing pressure increases linearly with the increase of fabric elongation basically when elongation is within 60%. The relaxation time of fabric make clothing pressure decrease, but the main decrease occurs within the first 30 minutes and only accounts for a very small proportion of all. Therefore, the effects of mechanical properties of fabrics on clothing pressure should be mentioned when we design clothing size for tight garments, which could provide basis for designing pressure comfort garments.

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